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Promoting Rigor in the Undergraduate Chemistry Curriculum

One goal of the ACS approval program is to promote excellence in the education and training of chemists in the U.S. As part of its charter, the ACS Committee on Professional Training (CPT) works to achieve this goal by evaluating undergraduate chemistry programs according to the Guidelines developed for this purpose. Some of the approval criteria, such as number of lab hours required for certified majors or faculty contact hours are relatively easy to measure because they can be easily quantified. More difficult to evaluate are other hallmarks of an excellent program, such as the rigorous experiences required of its students.

How does one define the rigor of an undergraduate chemistry experience? The CPT supplement on Rigorous Undergraduate Programs, which is available at www.acs.org/cpt, considers this question. The rigor of the curriculum typically builds as students move through the foundation courses to the higher level in-depth courses, therefore CPT uses in-depth course rigor as a proxy for the rigor of the overall undergraduate program. Although the level of rigor might be inferred from the depth and sophistication of the textbook used, the primary tools that the CPT uses to evaluate rigor are course syllabi, exams, and when appropriately required, student research reports.

Because the faculty have responsibility for the chemistry curriculum, the pedagogical approaches used for its delivery and assessment of student learning, they are primarily responsible for the rigor of a program. Instructional strategies that promote rigor include

- creating learning environments that actively engage student participation,
- facilitating the progressive development of student responsibility for learning throughout the curriculum,
- demanding critical thinking and multi-step problem solving in daily activities,

Rigorous learning environments require that students acquire skills in critical thinking and problem solving, and are able to synthesize knowledge and apply it to new situations.

- cultivating the development of an integrated understanding of chemistry throughout the curriculum, and
- providing regular faculty feedback on student work with attention to correctness of student work, detailed commentary on language skills, and commentary on the precision and correct use of scientific language, chemical notation and representation, based on accepted norms of the profession.

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problem solving, and are able to synthesize knowledge and apply it to new situations. Exams, exercises and laboratory experiences that require students to apply quantitative reasoning and demonstrate a mechanistic molecular understanding promote the development of student competencies. Students should be challenged to go beyond simple algorithmic problem solving or declarative knowledge to demonstrate a greater depth of understanding. In-depth course syllabi (if complete and well documented) can, for example, provide a sense of the learning environment maintained in the course and a level of the expectations placed on the student. Indications of rigor can be discerned from the course prerequisites and the methods by which student learning is evaluated for example, complex problem sets, project-based laboratories, extensive writing assignments, and the use of the primary literature.

In addition, in evaluating program rigor, the CPT also focuses on summative assessments of student learning such as exams. Exam items that require students to devise experiments to answer questions and that require articulation of chemical reasoning are excellent examples of rigorous assessments. Although multiple-choice items might be one component of a rigorous exam if special attention is paid to the construction of items that elucidate more than simple declarative knowledge, in general, the CPT expects that rigorous assessments, especially those used for in-depth courses, will not rely heavily on a multiple-choice format. Appropriately rigorous exam formats include

- free response questions,
- problems requiring multi-step quantitative reasoning,
- questions requiring demonstration of molecular mechanistic understanding of reaction pathways and chemical processes, and
- items that stretch students intellectually by requiring application of chemical concepts to new situations.

Rigorous laboratory experiences engage students in the process of experimentation, building high level skills in synthesis, measurement and/or computation while also developing in students the ability to design experiments and interpret their results in the context of the current knowledge. Students in rigorous chemistry programs are challenged to communicate effectively in a clear and concise manner using the language appropriate to the field and building on the established chemical literature.

Although there are several pedagogical approaches that can promote rigor in the curriculum, one of the most effective is a high quality undergraduate research experience. Many programs use undergraduate research as a capstone experience, although increasingly students are encouraged to engage in research early in their academic experience. Undergraduate research can be one of the most effective approaches for imparting student skills in problem solving, communication, teamwork, searching and using the chemical literature, and learning first hand how to safely and ethically practice chemistry. It also requires students to integrate knowledge to provide the quantitative or mechanistic understanding needed to answer questions or solve problems raised during the course of their research. Where research is used to meet the curriculum requirements of the ACS Guidelines, the CPT carefully evaluates the student research reports as an indicator of the rigor of the undergraduate research experience. The CPT's supplements on Undergraduate Research and Writing a Research Report provide additional guidance for programs and faculty research mentors on effective undergraduate research experiences and the preparation of student research reports.

How does a department assess its own 'rigor'? Excellent programs perform on-going self-assessment of the effectiveness of their curricula and pedagogies. Metrics that can be used to evaluate the overall rigor of a program are varied and may include student performance in capstone courses and in research, results achieved on nationally-normed exams, oral exams or exit interviews, and tracking student success after graduation. Regardless of the metric selected, the process of regularly assessing curricular rigor to guide future improvements is an effective strategy for establishing and maintaining a rigorous undergraduate experience.

Announcements

Congratulations!

The Committee congratulates the following schools on their newly ACS-approved bachelor's degree program in chemistry:

> Edinboro University of Pennsylvania
> Georgetown College
> Slippery Rock University of Pennsylvania

The current number of ACS-approved programs is 667.

CPT Open Meeting

CPT will hold an open meeting at the ACS National Meeting in San Diego on March 25, 4-5:00pm. The location has not been determined yet.

Revisiting the 2008 ACS Guidelines

As the chemistry community is approaching the fourth anniversary of the adoption of the 2008 guidelines, the ACS Committee on Professional Training is beginning the process of reevaluating these guidelines in preparation for a new edition. The 2008 guidelines represented a large departure from previous editions in a number of ways, and the Committee is interested in how the 2008 guidelines have impacted you and your programs.

Areas where the current economic situation has made the requirements more difficult for some departments to meet or where there were departures in the 2008 guidelines compared to earlier editions include:

- ***The curricular requirements:*** The curricular requirements in the 2008 guidelines were designed around breadth requirements that provide overview coverage of five chemistry subdisciplines: Analytical, Biochemistry, Inorganic, Organic and Physical Chemistry, and four in-depth courses that build on this foundation. The required total lab hours were set at 400 laboratory hours beyond general chemistry and must provide students laboratory exposure in at least four of these five chemistry subdisciplines. To give programs greater flexibility in their in-depth course offerings, the areas covered by the in-depth courses are flexible, and the content of the in-depth experience is up to the department. Some of the laboratory and in-depth course work can be in the form of independent research, although a department must offer at least four in-depth courses annually
- ***Student skills:*** The need for student skills in the areas of problem solving, effective use of chemical literature resources, laboratory safety, oral and written communication, teamwork, and the ethical practice of science is emphasized in the 2008 guidelines
- ***Personnel:*** The guidelines include limits on the student contact hours for which faculty and instructional staff may be scheduled for on a weekly basis. There are also requirements for the minimum fraction of faculty who hold PhD degrees. Such requirements have been a part of earlier editions of the guidelines, but averaging of contact hrs is now permitted with up to 17 contact hours allowed in one term provided the average over the academic year is 15 hours or less.
- ***Infrastructure:*** The program must maintain a diverse holding of modern instruments, including an NMR spectrometer, for hands-on use of students in the laboratory and research. The guidelines also list requirements for journal access and literature searching.
- ***Department self-evaluation:*** The 2008 guidelines include a requirement that programs describe their efforts in self-evaluation and how they use feedback from this process to improve their program (or alternatively better serve their students).
- ***Applications and reporting:*** Along with the revised guidelines, in 2008, new procedures were put in place for the application process for schools that are interested in becoming approved. The five-year reports were also modified as well as the procedures for communication between The Committee and departments at the time of the five-year reports.

The complete 2008 ACS Guidelines booklet can be found on the ACS webpage at http://www.acs.org/cpt.

In early 2012, the Committee on Professional Training will begin the process of reevaluation of the guidelines in preparation of a new edition. The Committee welcomes your comments and suggestions on any of the above areas or other aspects of the guidelines. This input can be provided by email to cpt@acs.org. We are also planning a series of symposia and open meetings at the national ACS meetings to discuss proposed guidelines revisions over the next year or so, and hope to hear from you at one of these sessions.

Certificates for ACS Certified Graduates

Chemistry majors who receive a baccalaureate degree from an ACS-approved program and complete a curriculum consistent with the ACS Guidelines may be certified to the Society by the head or chair of the approved department. In 2012, we will be sending certificates to all certified graduates. If you would like to have certificates available for presentation to your certified graduates, please contact the office by email at cpt@acs.org.

ACS Task Force on Scientific Foundations for Future Physicians

In 2009, the Association of American Medical Colleges (AAMC) and the Howard Hughes Medical Institute (HHMI) released a report entitled *Scientific Foundations for Future Physicians* (SFFP: see https://www.aamc.org/download/64442/data/08209 execsummary.pdf). This report, produced in response to "concerns about the science content in the current premedical and medical education curricula," emphasizes competencies for premed students rather than mandating specific courses for admission to medical school.

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One result of SFFP is a major revision of the Medical College Admission Test (MCAT) by the AAMC (see https://www.aamc.org/initiatives/mr5/), to be released in 2015. (A preview guide is online at www.aamc.org/mcat2015.) Another result is the funding by HHMI of an Experimental Collaboration (termed NEXUS) among four universities to develop innovations in their science offerings for premed students.

SFFP presents both opportunities and challenges for the chemistry community. In order to advise and coordinate ACS efforts related to this report, a Task Force has been convened, comprised of members of the Committee on Professional Training and the Society Committee on Education. The efforts of the Task Force are concentrated in four areas:

- Maintain contact with AAMC as they move forward with the revision of the MCAT and work with member medical colleges to modify admission requirements in response to SFFP.
- Maintain contact with HHMI and its grantees as they develop curricular innovations in response to SFFP.
- Develop information on innovative approaches already being introduced by chemistry programs to better meet the needs of pre-professional students, particularly around the teaching of general and organic chemistry.
- Develop means to disseminate information on the above activities to the chemistry community.

In the coming months, details of these efforts will be reported via several sources, including symposia at venues such as the fall, 2012, national meeting of the ACS and the 2012 Biennial Conference on Chemical Education. If your institution offers a chemistry curriculum for pre-professional students or you have ideas regarding ACS's role in addressing the recommendations in SFFP, please contact the Task Force at sffp@acs.org.

Highlights from the Symposium Celebrating 75 Years of the ACS Approval Program

CPT Looks to the Future

This year marks the 75th anniversary of the founding of the ACS Committee on Professional Training (CPT) and the ACS approval of undergraduate chemistry programs. To mark this anniversary, a half-day symposium titled "75 Years of the Committee on Professional Training (CPT): It's Not Just About Approval" was held in March at the 241st ACS National meeting in Anaheim, CA. This symposium provided a look backwards at the history of the committee and the ACS approval program, and at issues and opportunities facing chemistry, including the central position of chemistry in the increasingly interdisciplinary scientific arena, the participation of members of underrepresented groups in our discipline and the importance of global participation in the chemistry enterprise, especially important in this the International Year of Chemistry. This article presents an overview of the symposium presentations. The archived presentations can be accessed at http://www.softconference.com/ACSchem/slist.asp?C=4321#TID14695.

The symposium was introduced by ACS president Dr. Nancy Jackson who provided opening remarks. This was followed by a presentation by two former CPT chairs Sally Chapman, Barnard College, and Will Polik, Hope College, titled *"History of the ACS CPT Guidelines and approval process"*. In her talk Prof. Chapman described the origins of the ACS approval program during the depression stemming from concerns about the unemployment of chemists. After three years of study the committee released in 1939 its minimum standards for approval. The first list of ACS approved schools published in 1940 included 56 schools. In the first decade of the ACS approval program 750 school visits were conducted by 120 visiting associates. The first pamphlet for revised standards was published in 1949, followed by major revisions released in 1954, 1962, 1977, 1988, 1992 and 2008. In 1953, the first edition of the ACS Directory of Graduate Research was published, and in 1957, the first CPT report on Doctoral Training in Chemistry appeared. Prof. Chapman also described the important role of CPT in collecting and disseminating data through reports, including those on enrollment and diversity.

Prof. Chapman noted that the committee has benefited from a distinguished and dedicated membership that has included many of the most notable chemists of the past 75 years. CPT members who have gone on to serve as ACS President include Roger Adams, Arthur C. Cope, W. Albert Noyes, Jr., Eli M. Pearce, and Joseph Francisco. Ten former committee members have received the Priestley medal. Contributing to the effectiveness of the committee has been the dedicated service provided by the staff support provided to the committee, which has had only five secretaries over the past 75 years.

In his presentation *"Mandates from the ACS, the profession, and from chemistry: Excellence and rigor"*, by Carlos Gutierrez, California State University - Los Angeles, Prof. Gutierrez described the key characteristics of a successful chemist. These attributes include chemistry content knowledge and laboratory skills, plus skills in effective communication, a strong work ethic, creativity, resilience, curiosity, a habit of success, and the ability to apply molecular science to a host of other disciplines. Starting with these qualities, Prof. Gutierrez explored the possibility of reverse engineering the chemistry curriculum de novo in a way that more authentically educates undergraduate students and motivates them to excellence. He argued that "Chemistry should be taught

Announcements

Changes in CPT Membership

In 2011, three new members were appointed to CPT: Dr. Ronald Brisbois, Dr. Laura L. Kosbar, and Dr. Thomas J. Wenzel. Dr. Brisbois is a Professor in the Department of Chemistry at Macalester College. Dr. Kosbar is a Research Scientist in Chemistry at IBM T.J. Watson Research Center. Dr. Wenzel is a Professor in the Department of Chemistry at Bates College.

The Committee would like to express its very special appreciation for the many contributions of the following members, who concluded their terms of service on CPT at the end of 2010:

- Dr. Robert A. Copeland
- Dr. Robin L. McCarley
- Dr. William F. Polik

and at the end of 2011:

- Dr. Cornelia D. Gillyard
- Dr. Nancy S. Mills
- Dr. Barbara A. Sawrey

the way that we do chemistry". Research or research-like experiences should be embedded in courses with increasing sophistication as students move through the curriculum. How do we nurture students' innate interest in chemistry? Prof. Gutierrez answered "My research students and I do chemistry because we like it, because we are good at it and because it gives us great pleasure". Students should be trained to ask questions, take intellectual risks, and be skeptical.

Prof. Gutierrez also noted the importance of cognitive diversity to science positing "Excellence must be the denominator of all participation". This theme of diversity was expanded upon by Rigoberto Hernandez, Georgia Institute of Technology, in his presentation *"Chemistry's changing face: Increased diversity correlates with excellence"*. Prof. Hernandez presented data that showed that the diversity of chemistry students graduating with Bachelor's degrees has increased, with about 20% of chemistry degrees awarded to underrepresented students. Roughly one in six of these underrepresented students go on to achieve a Ph.D. degree in chemistry, however, the likelihood that one of these BS graduates will go on to a faculty position at a top 50 research university is only about 1%. As a community we need to explore ways in which this rate can be increased.

Prof. Hernandez also raised the question whether there is an objective function for merit with respect to diversity. Talented candidates are available, they just need to be recruited and empowered to be successful. Certainly implicit bias plays a role; there is evidence that applications with identical resumes, other than race, give rise to preferential selection of white candidates. Very small differences treatment over the course of a career can accumulate, having major consequences in salary, promotion and prestige, including advancement to leadership positions. To address these challenges, OXIDE: Open Chemistry Collaborative in Diversity Equity (www.oxide.gatech,edu) has been by established Prof. Hernandez at Georgia Tech. Oxide will be addressing diversity issues by working with department heads and other organizations to increase the diversity of the faculty of chemistry doctoral programs.

In his presentation Peter Dervan, California Institute of Technology, spoke about the *"Interdisciplinary nature of chemistry"*. Prof. Dervan provided a personal perspective on the history of this topic as well as his view of what the future may hold. In the past, interdisciplinary chemistry meant crossing between the chemistry subdisciplines. The development of NMR, which came through physical chemistry from physics, and gas chromatography, which grew out of analytical chemistry, allowed the development of the new field of physical organic chemistry and changed the way that organic chemistry is taught. In the 1970s chemistry and biochemistry truly came together as a single discipline, again largely enabled by technological advances. X-ray crystallography and multidimensional NMR experiments allowed detailed structural analysis of proteins and DNA. This union was cemented by solid phase synthesis, which enabled the synthesis of proteins, DNA and RNA in pure form, sequencing, which allow their analysis in biological systems, and the discovery that RNA can act as a catalyst. In the decades that followed, chemistry has had a profound impact on biology, evolving into the field of chemical biology and the emerging areas of synthetic biology and astrobiology.

Prof. Dervan noted that chemistry is absent from the names of the fields synthetic biology and astrobiology and posed two questions that should be considered for the future of our profession. Does chemistry have a brand? Does chemistry have a business plan? In answer to these questions, Prof. Dervan presented an overview of a recent article by George Whitesides and John Deutch (Nature, 409, 21 (2011)). This article argues that in the future, the process

of doing chemistry may be reinvented becoming more problem-focused, stimulating curiosity and making fundamental discoveries in the process of addressing complex global problems. The education challenge is how to develop the tools of curiosity in our students.

ACS President Joseph S. Francisco, Purdue University, furthered this discussion in his presentation *"Global perspective on the future of chemistry"*. A key engine of globalization is technology and education needs to prepare students for a global marketplace. Global skills are important in getting the job, keeping the job and getting ahead in the job. President Francisco recently organized a meeting of chief technical officers (CTOs) from the chemical industry and leading academic chemists to discuss the skill sets valued by the chemical enterprise for today's global marketplace. One surprise coming out of this discussion was that CTOs are now looking for students who have one or more foreign languages. CTOs also indicated that when reviewing resumes of recent graduates they look for "global readiness". Global readiness skills can be developed by providing students with an opportunity to live and work in another country while pursuing their degree. Prof. Francisco asked whether it would soon become normal for chemistry students, researchers, and professionals to spend a part of the year in another country, and whether the national chemical society has a role in enabling this transnational mobility. Global problems centering on energy, food, health and the environment will require global solutions, and scientists equipped to tackle them.

Jeanne Pemberton, University of Arizona, wrapped up the session with a presentation titled *"CPT: The group you love to hate"*. She noted that CPT membership is representative of the broad chemistry community who are stakeholders in the education and training of chemists. The ACS approval program is unique among scientific disciplines. Tension between CPT, the academic community, industry and other ACS units is an essential element of the success of ACS approval program, and has contributed to its effectiveness over the past 75 years. CPT has a quasi-judicial role in administering the approval program. CPT develops the ACS Guidelines, which define the Committee's view of best practices in chemistry education. Prof. Pemberton described the incredible diversity of institutions to which the Guidelines must be applied. Of the roughly 1100 institutions offering baccalaureate degrees in chemistry in the US, around 675 hold ACS approval. ACS-approved schools include institutions with chemistry faculties ranging in size from 4 to more than 60. These programs produce graduates ranging from 2-3 to more than 250 a year. The budgets and infrastructure resources of these institutions also vary greatly. This diversity of programs and academic institutions is an important attribute of the US educational system. Although programs at doctoral universities grant large numbers of degrees, these account only for about 50% of the baccalaureate degree recipients in chemistry.

Prof. Pemberton noted CPT's desire to be inclusive rather than exclusive in equitably administering the approval program, although achieving an equitable implementation can be challenging considering the diversity of the institutions involved. The ACS Guidelines must also accommodate a dynamically changing discipline, which has led to an approach of continuous reform. The 2008 Guidelines grew from a CPT discussion of what factors constitute an excellent undergraduate program and a rigorous educational experience, discussion that is now summarized as supplements on these topics. Prof. Pemberton noted that research universities play an important role in the ACS approval process, although these programs may question their reasons to participate. Quoting an article by Prof. Marjorie Caserio (SPIE Proc. 978, 132-135, 1988) "If the top research universities should withdraw from the program, the losers will be the many schools who are motivated by and take pride in the fact that they rank with these universities as having an ACS-approved chemistry program". Prof. Pemberton suggested that for the 75 years our profession has benefited from the common denominator of excellence provided by ACS approval and that research universities have a responsibility to participate in the approval program as part of their stewardship of the profession.

Updated Supplements Available!

The requirements for program approval and student certification are described in Undergraduate Professional Education in Chemistry: ACS Guidelines for Evaluation Procedures for Bachelor's Degree Programs. The Committee on Professional Training also publishes supplements to these guidelines that provide more detailed advice to departments that wish to develop specific aspects of their chemistry program. The following supplements have been updated and posted on the CPT web pages at http://www.acs.org/cpt.

- Undergraduate Research
- Preparing a Research Report
- Teaching Professional Ethics

ACS Committee on Professional Training 2011

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